TECHNICAL MEMORANDUM (NASA) 48

MINI-L LORAN-C RECEIVER

A low-cost prototype Loran-C receiver front-end has been designed and bench-tested. This receiver concept provides outputs to interface with a microcomputer system. The development of sensor and navigation software for use with the Mini-L system is underway.

by

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I. INTRODUCTION TO LORAN-C

Loran-C is a radio navigation system based on measuring time differences between pulse groups transmitted by master and slave stations at 100 kHz. A hyperbolic time-difference grid is produced in the user area over a range of 1000 miles or so with a coverage as illustrated in Figure 1 for the North American region (as of March 1977). Expansion is planned with additional station chains to cover the continental USA and Gulf Coast areas by the early 1980's. Loran-C navigation charts and tables are published by the U.S. Defense Mapping Agency.

High radiated power is transmitted from each station (200 kw to 1 megawatt) such that most users will have a positive signal to noise ratio in their receiver for a 20 kHz bandwidth. Signal levels measured in Ohio over a 24-hour period in winter are illustrated in Figure 2. These data were obtained with a 1 meter vertical whip antenna mounted at rooftop level in an urban environment. In the particular case illustrated, the signal from the Master (M) in North Carolina, Slave (Z) in Indiana, and Slave (Y) in Nantucket provide quite good signals for the entire 24-hour period. The signals from the Florida (W) Slave are weaker during daylight hours and those from Newfoundland (X) Slave are beyond the recommended usable range (> 1000 miles). The dotted line in Figure 2 at the 50 dB above 1 μV for 20 kHz bandwidth is the typical atmospheric noise level point for the relatively noisy urban monitoring environment in the receiver used for this example.

One microsecond or better precision in navigation is observed with Loran-C. Some marine users claim repeatability of 100 feet in locating reference buoys with sophisticated Loran-C receiver systems. Airborne systems are reported to have similar precision. Presently most receivers are expensive (above $2000), and there is a need for the development of some low-cost front-end and sensor processing devices.

II. PULSE FORMAT

Figure 3 is an illustration of the shape of each transmitted pulse which is controlled at the transmitter. The leading edge for the first 65 microseconds is very carefully shaped such that the user can identify the 3rd 100 kHz zero crossing at the 50% envelope amplitude point when using a hard-limiting type of receiver input circuit. It does not matter if a receiver chooses the 2nd or 4th zero crossing, but what is important is that the receiver determines the same relative early zero crossing for all signals used in the time-difference measurements. By measuring one of these early zero crossings before 65 microseconds, it is possible to largely eliminate skywave contamination of the pulse which starts to rise after the first 30 microseconds in the user coverage area. The stations transmit groups of pulses as illustrated in Figure 4 with a known coding Time Delay (TD) which enables a receiver to predict when to start looking for the time difference in comparing a particular slave with the master. The pulses are also phase-coded so that further sophistication in identifying stations and eliminating interference is possible in the receiver processor. Further details on the phase-coding are found in the U.S. Coast Guard CG-462 "Loran-C User Handbook".

The Group Repetition Interval (GRI) for a particular chain is a constant, 99300 μsec for the East Coast USA and 99400 μsec for the West Coast USA chains. Thus a timer in the receiver sensor processor is usually set to one of these known rates for navigation in the local user area. The GRI and slave TD's become the initial conditions or calibration data to tell the receiver processor what time differences to measure when selecting a particular Loran-C chain.

Another compatible pulse format with 16 pulses per station is used in the military Loran-D system. These will often be observed in Loran-C receivers but the sensor processor can be arranged to ignore or eliminate this type of cross chain interference. The spacing between pulses within one normal transmitted Loran-C group is 1 ms for each of the 8 slave pulses with an extra 1 ms gap for the 9th pulse to identify the master transmission. In contrast, the Loran-D pulse groups are spaced 0.5 ms apart.

Skywave contamination of Loran-C can sometimes result in confused identification of the proper measurement starting point or the appearance of double and even triple pulses depending on the range to the transmitting station. However, these are usually not at exactly the 1 ms spacings of the desired signals for Loran-C (or 0.5 ms for Loran-D), hence the receiver sensor hardware and/or software can eliminate this type of interference. With a very sophisticated processing system it is possible to identify skywaves and use Loran-C signals at extreme ranges like 3000 miles or more on a world-wide basis. However, the usual receiver is designed to work only with the ground wave signals at ranges up to 1000 miles.

III. INTEGRATED CIRCUITS FOR LORAN-C RECEIVERS

The advent of single chip IC's for compact AM-FM receivers provides a possible component for use in Loran-C receiver RF front-end circuitry. One choice is the Fairchild μA 721 AM-FM receiver subsystem IC illustrated in block form in Figure 5. This chip contains four functional blocks and a bias regulator which can be converted to Loran-C system use according to the following table:

ORIGINAL INTENDED USE	LORAN-C USE
1. AM Oscillator-Mixer	Q-Multiplier for input rejection trap
2. Amplifier I, 500-1600 kHz AM -RF	100 kHz, 1st RF amplifier stage
3. Amplifier II, 455 kHz AM -IF	100 kHz, AGC controlled limiter
4. FM-IF Amplifier-Limiter-Detector, 10.7 MHz	100 kHz, limiter-autocorrelator

A block form of a Loran-C receiver based primarily on the μA 721 IC is shown in Figure 6. This receiver uses hard-limiting with AGC derived from an autocorrelation detector. An autocorrelator provides a very marked improvement in detection of pulse envelopes over the performance of a conventional diode AM detector. Loran-C receivers are required to have a relatively wide bandwidth of 20 kHz or so in order to pass the rise-time of the transmitted pulse envelope. Standard 455 kHz IF transformers with added tuning capacitance provide broadband 100 kHz coupling transformers for the circuit of Figure 6. More complete details of a prototype Loran-C front-end system are found in an appendix to this report.

A complete front-end for Loran-C also requires some form of interface circuitry to a typical microprocessor for the time-difference data reduction. As suggested in Figure 6, an external 1 MHz crystal oscillator drives a programmable divider chain which generates BCD words for each Loran-C pulse.

IV. MICROCOMPUTER PROGRAMMING PROBLEMS

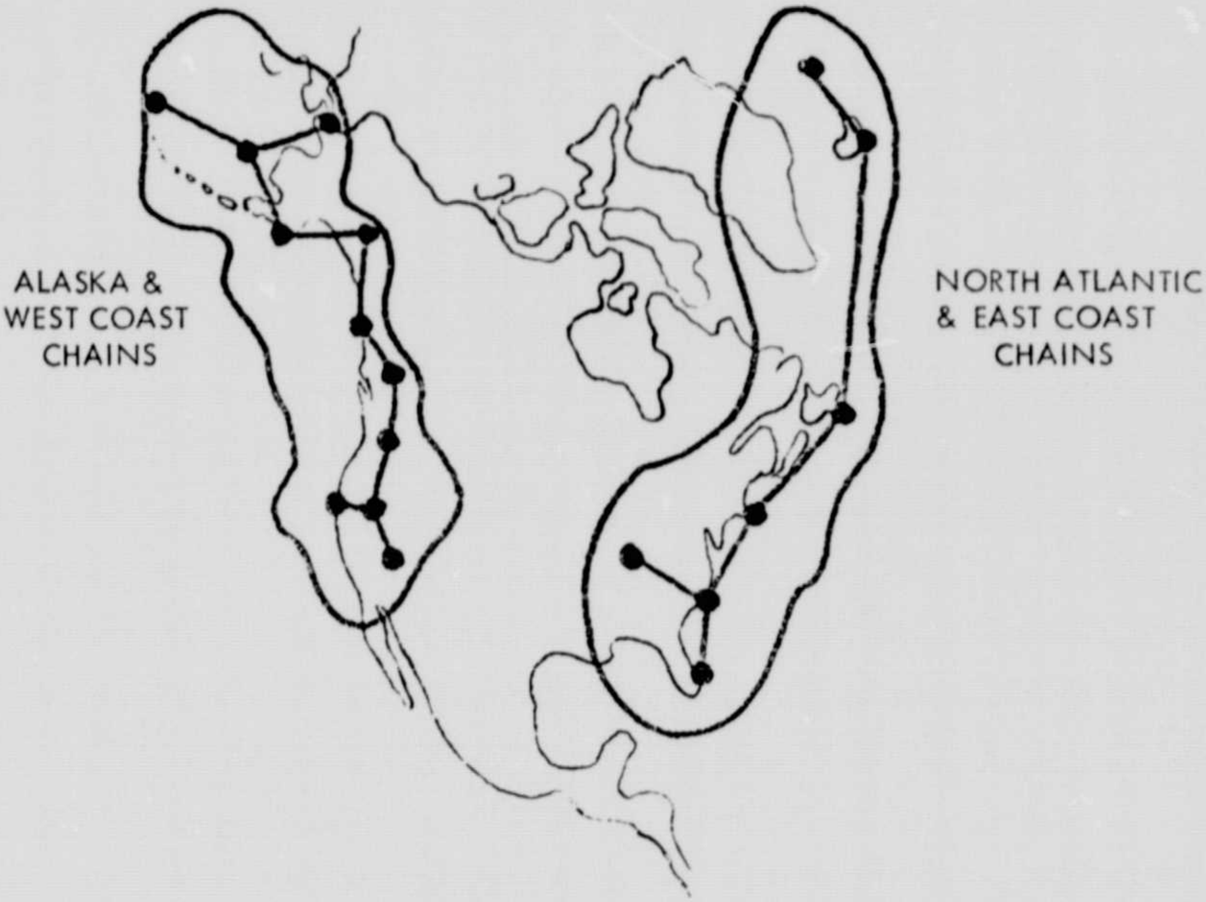
The microcomputer attached to the output of Figure 6 needs to be programmed to select the desired chain rates and time delays for the particular Loran-C system used. Also required is an averaging or cross-correlation of the time difference of the 8-9 pulse groups, a display of the resulting filtered time differences as microsecond intervals for marine users, and conversion of the microsecond readings to rho-theta presentation for airborne users. These programming tasks are under development with KIM-1 and JOLT microcomputer systems using MOS Technology 6502 microprocessors and up to 4k of memory. A future report will present the programming problems in much more detail.

V. SUMMARY

A brief description of the Loran-C system is presented with a suggested receiver based on a standard AM-FM integrated circuit chip. Construction details of the Mini-L Loran-C prototype front-end are contained in an appendix prepared for those skilled in electronic circuit fabrication arts. The Mini-L system has been bench-tested for approximately 500 hours under a variety of reception conditions. The Mini-L concept combined with a microprocessor system appears to be a promising approach to the development of truly low-cost Loran-C receivers for the marine and airborne user.

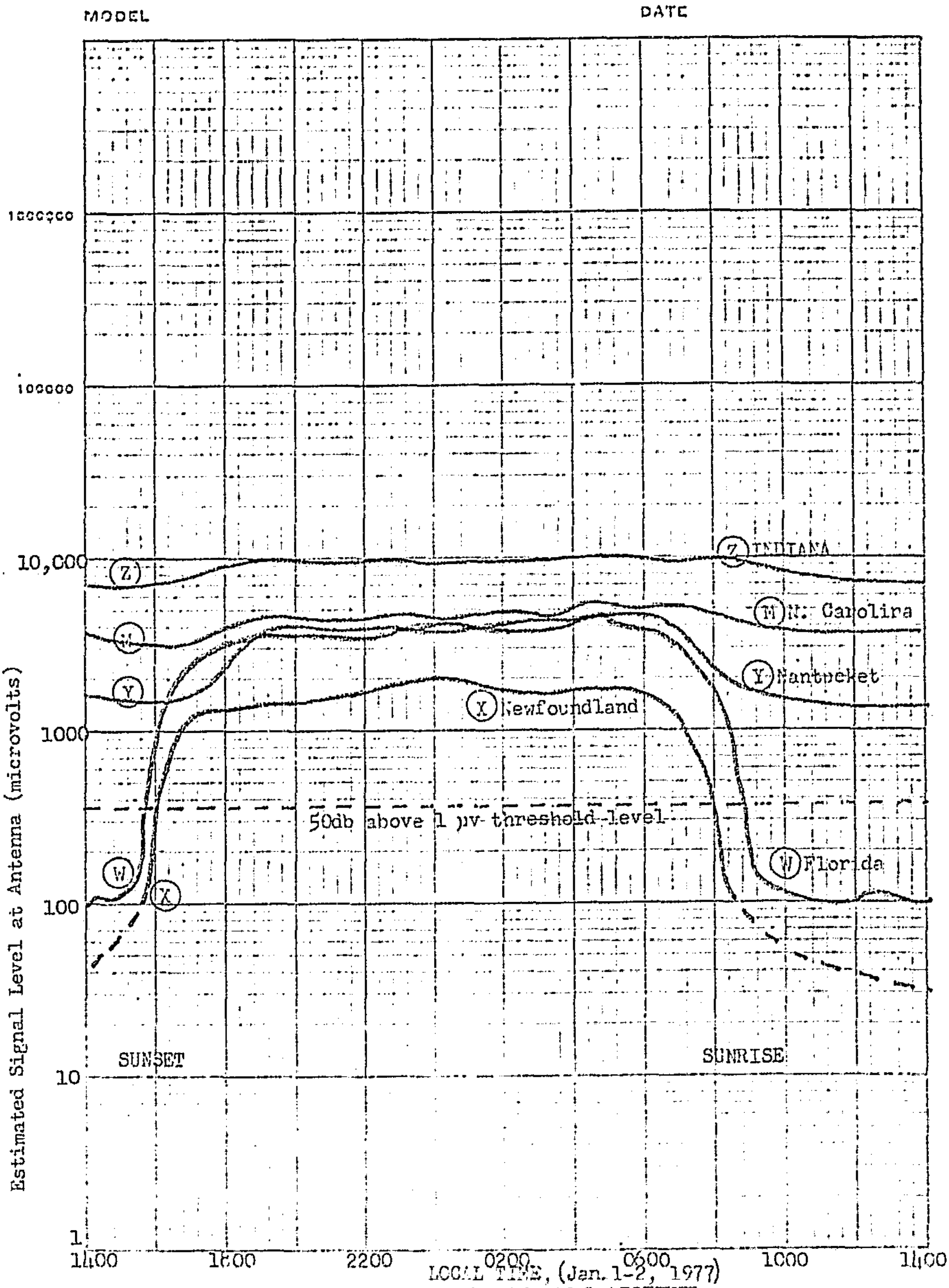
VI. ACKNOWLEDGEMENTS

This receiver concept was supported by NASA Langley Research Center Grant NGR 36-009-017 on the continuing development of VLF navigation techniques for the general aviation community. The encouragement of Dr. Richard H. McFarland, the advice of Dr. Robert W. Lilley, and the circuit board production help of Lee Wright and James Nickum are gratefully acknowledged. The help of Mr. Charles R. Gray of Fairchild Camera and Instrument Co. Mountain View, California, is particularly appreciated in obtaining samples of the μA 721 integrated circuits used in this Mini-L receiver development.



NORTH AMERICAN LORAN-C COVERAGE (MARCH 1977)

FIGURE 1



EAST COAST LORAN-C IN MINI-L RECEIVER

FIGURE 2

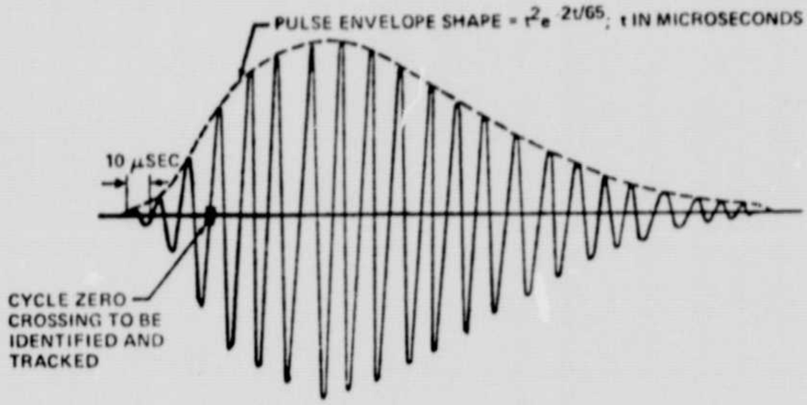


FIGURE 3. LORAN–C PULSE

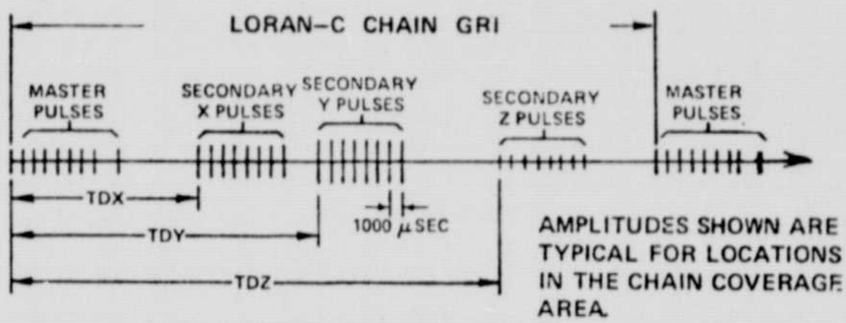


FIGURE 4.

EXAMPLE OF RECEIVED LORAN–C SIGNAL

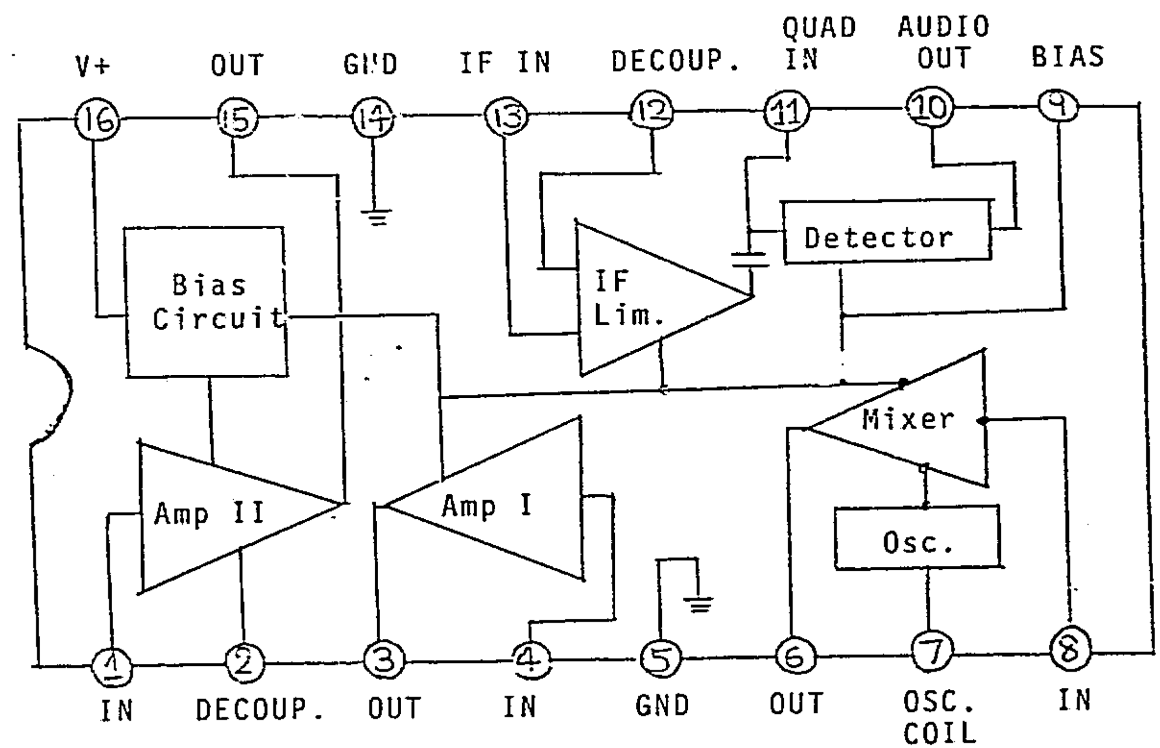
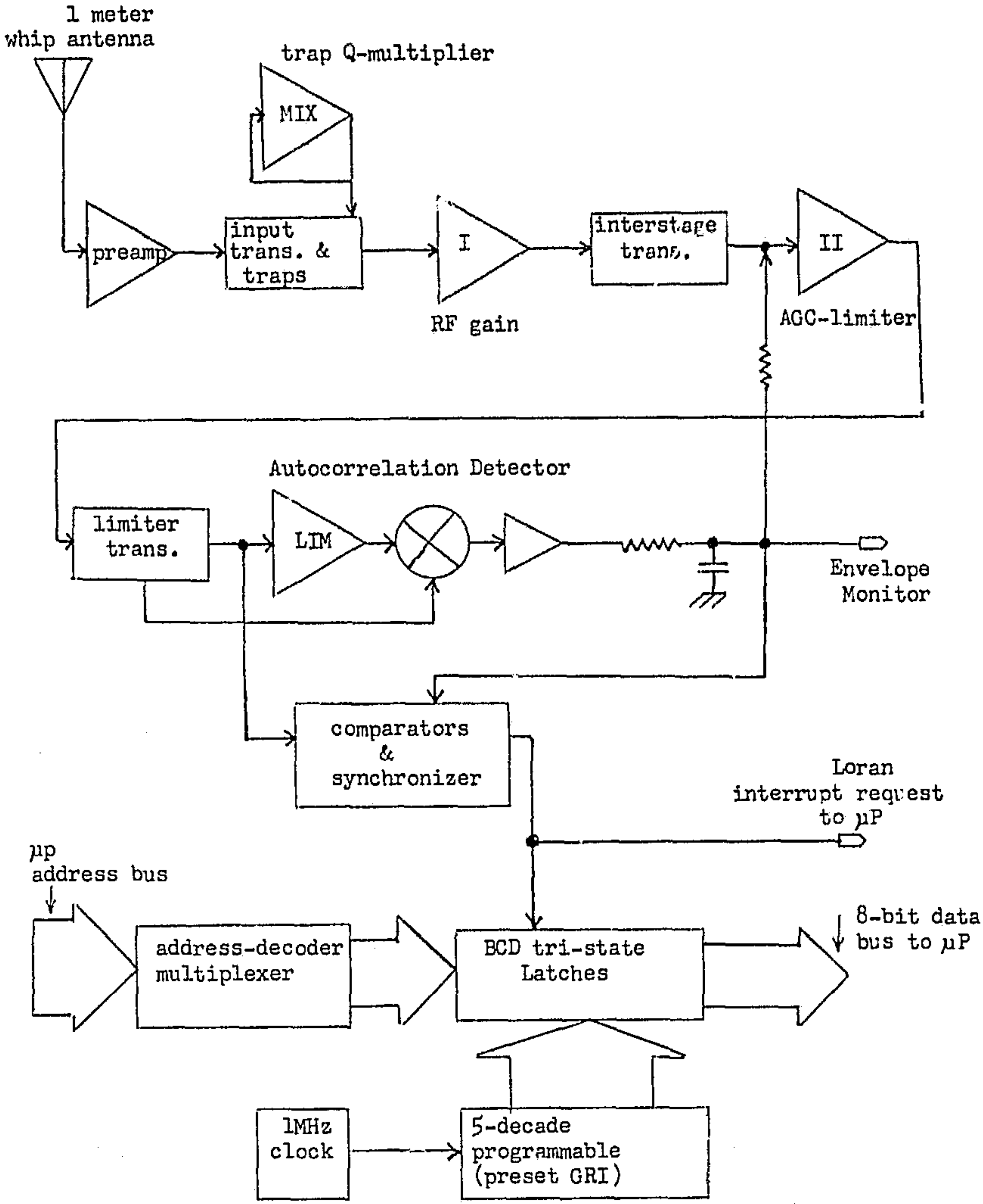


FIGURE 5
uA721 BLOCK DIAGRAM



MINI-L BLOCK DIAGRAM

FIGURE 6

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MINI-L EXPERIMENTERS MANUAL

R.W. BURHANS

A low-cost prototype Loran-C receiver circuit board has been designed for use as an input sensor with microprocessor systems. Mini-L is both a hardware and software experimenter's device and is not intended as a finished navigation system. Rather, it is designed so that those skilled in the electronic circuit fabrication arts can study the Loran-C navigation system by actual use of on-the-air signals for development of future computer-controlled timing and navigation devices. A set of circuit boards for the basic front-end and antenna preamplifier are available.

February 1977

MINI-L LORAN-C EXPERIMENTERS GUIDE

Basics Loran-C is a 100 kHz radio navigation system that provides the user with accurate position information anywhere within the signal coverage area. For details on Loran-C the beginner should obtain one or more of the references listed at the end of this guide. The Loran-C format consists of a group of 9 pulses separated by 1ms intervals from the master station and 8-pulse groups from each slave. There are three or more stations in each chain and a minimum of three stations are available for position location purposes in the coverage area. Loran-C can provide 1/4 nautical mile position fixing accuracy with a precision receiver system. At present, receivers are available selling in the $2k to $20k class, and many of them are based on microprocessor data reduction systems attached to an RF front-end. The pulses transmitted by each station are very carefully shaped such that in the user field, the measurement of the third cycle of the actual 100 kHz carrier wave is possible. This corresponds to the 50% rise time of the signal envelope occurring 30 microseconds after the station turns on. By measuring this point, it is possible essentially to eliminate sky-wave contamination of the signal which rises after the first 30 microseconds in most of the user field.

The receiver processor determines the time difference of arrival between the pulses sent out by the master and slave transmitters. These time differences are plotted as hyperbolas on local area navigation charts or tables available from the USCG or Department of Defense Mapping Agency.

SIMPLIFIED MINI-L FRONT END SYSTEM FOR USE WITH MICROPROCESSORS

For the potential user who already has a microprocessor or microcomputer system and is reasonably skilled in the electronic circuit fabrication arts, a very simple receiver system has been devised which is capable of providing timing data to within about 1 microsecond accuracy. The receiver is based on one of the most recent (in 1977) AM-FM receiver chips available, the Fairchild μA721. This single chip provides an autocorrelation detector for the Loran-C pulse envelope with single pulse, fast attack-slow decay, AGC characteristics over a wide range of signal levels. Mini-L is essentially a hard-limiting RF front-end which provides a single sample of the carrier wave at the estimated 50% point. These 10 microsecond pulses, one for each Loran-C transmitted envelope, are used by the microcomputer as interrupts to determine the differences in the time of arrival of the signals. The Mini-L front-end does not provide navigational data; rather, it only generates signals in a suitable digital format which the microcomputer user must manipulate to suit his particular interests. Thus Mini-L is what we call an RF front-end for the Loran-C signal format.

PREAMPLIFIER

An E-field short whip or wire antenna with a length of 30cm to 10 meters is sufficient to receive the Loran-C signals when a high impedance amplifier is connected to the antenna. A simple impedance converter of this sort is shown in Figure 1. The circuit is mounted in a weatherproof box with a feedthru insulator or fitting for the antenna, and a coaxial cable connector for the signal back to the receiver. In this circuit the power for operating the JFET amplifier comes up the same cable that the signal goes back down to the RF front-end. UHF type fittings (S0239) as used in CB radio systems are adequate for both the antenna terminal input and output when provided with some weatherproof sealing compound such as silicone bathtub caulk. A short whip antenna wire or rod fastened to the center conductor of a PL259 type UHF cable fitting with epoxy cement to insulate the wire from the outer shell, will suffice for the antenna when it is mounted in the clear.

Long wire antennas can also be used. However, it is wise to have a coated or insulated wire to reduce precipitation static (p-static) caused by water, ice, or snow particles hitting the conductive antenna surfaces. A suitable coated short whip antenna is also advisable in most installations. Coatings in commercial systems are a special fiberglass formulation, polypropylene, or even vinyl type insulation.

Figure 2 is an illustration of a simple PC board layout for the preamplifier of Figure 1.

RF FRONT-END

Figure 3 is the circuit diagram of the μA721 which forms the primary component of this Loran-C front-end. The Loran-C signal format is such that it is necessary to have a 20 kHz bandwidth in order to determine the pulse envelope rise time or to pass this envelope as transmitted. This implies a single tuned circuit with a Q of 5. However, Loran-C users also find that interference from CW and FSK carriers on 88 kHz and 119 kHz for the East Coast chain, and on 60 kHz and 122 kHz for the West Coast, are troublesome in the receiver processors. The trap Q must be reasonably high in order to reject the signal but not alter the Loran-C rise time. A T-Notch type of trap circuit is shown in Figure 3 for both filters, following the broad tuned input circuit. The transformers used are all 455 kHz IF transformers normally used in transistor radios. The types suggested, resonate at 100 kHz with about .0033 mf (3300 pf) additional capacitance across the main tuned circuit. T1, T4, and T5, all have this same 100 kHz resonating capacitor which should be a polystyrene type for best long term tuning stability.

The T-Notch filters use a split capacitor, two .01 mf in series for the low frequency trap and two .005 in series for the high frequency trap with the center junction connected to an adjustable resistor to ground. The resistors are adjusted with the aid of a signal generator and frequency counter coupled to the front-end input terminal through a suitable attenuator. The slugs on T2 and T3 are adjusted for a null using an oscilloscope for a null detector at pin 4 of amplifier 1.

For alignment, a triggered sweep oscilloscope, 100 kHz tunable function generator, frequency counter, and DVM are desirable minimum test equipment. The signal source is connected to the IN terminal through an isolating capacitor (to eliminate DC feedback into the function generator) and suitable attenuator. The slug on T1 is adjusted to peak the response as measured at pin 4 of the μA721, at about 98 kHz. The slug on T2 is then adjusted for a null at 88 kHz and the Q trim pot adjusted for lowest feedthru. The slug on T3 is then adjusted for a null at 119 kHz and similar minimum feedthru with the Q adjust pot trimmer. The procedure is repeated to obtain a closer fit which should look something like Figure 4 only with less attenuation in the higher and lower sidebands. T1 is offset slightly from 100 kHz to compensate, in this East-Coast case, for the fact that 88 kHz is only 12 kHz removed from the Loran-C center frequency. The next step is the alignment of T4 with a low setting of the RF gain trim pot by measuring at pin 3 of amplifier I. The response should start to look very similar to Figure 4 at this point. It may be necessary to go back and forth through the adjustments several times and to stagger tune T1 and T4 somewhat below and above, respectively, the 100 kHz Loran-C center frequency. Both T1 and T4 are loaded appreciably by the circuit to purposely make these input and interstage transformers rather broadband. If different IF transformers are substituted, it might be wise to place a resistor in parallel with the main tuned circuits to broaden further the bandwidth.

The Q-Multiplier stage using the mixer part (MIX) of the μA721 chip can be used to increase the Q of the 88 kHz trap. This will improve the depth of the null and widen the low end response but the .01 caps used should be mylar types of even polystyrene for best long term temperature stability at the much higher notch Q. The adjustment of the slug on T2, the Q-trim pot, and the Q-multiplier trim pot are all interacting and should be conducted with care. A very stable signal source and frequency counter for checking the null depth points are required. The Q-multiplier is essentially out of the circuit when the adjust pot (500 ohms) is turned to the ground end with no power to the MIX stage.

The remaining adjustment of the T5 limiter transformer is best done with actual on-the-air Loran-C pulse signals. The receiver is connected to the preamplifier through a suitable coax cable with the antenna mounted outside somewhere likely to be in the Loran-C RF field. The RF gain control is turned towards the low (grounded) end. The threshold adjust pot is turned from the +V (minimum sensitivity) end slowly up towards the center of its range. Some pulse type signals should start to appear on an oscilloscope connected to the Envelope scope monitor point just ahead of the AGC bus of Figure 3. The sweep rate of the scope should be adjusted for 5 to 10 ms/cm so that a whole cycle of the East Coast 99300 microsecond group repetition interval (GRI) can be observed. As the threshold pot is slowly advanced, it should be possible to successively observe more and more discrete Loran-C pulse signals. A maximum sensitivity point where the Loran-C signals and receiver noise are all limiting at about the same level may be observed. The threshold control pot setting that is on the low side, towards the +5V end of the pot, will give the best results. The goal here is to find a reasonable low sensitivity operating point with low RF gain such that one or more Loran-C signals are observed, then peak the slug in T5 for maximum amplitude on one of the weaker Loran-C signals which is not full limiting. (NOTE: West Coast observers can use the West Coast Loran-C chain which has a 99400 microsecond GRI, and sometimes midwestern observers see both chains skipping past each other in the sweeps of the scope used.)

The final settings of the RF gain trim and AGC threshold pot interact somewhat. The AGC characteristics are shown in Figure 5. The μA721 chip amplifier II was designed to use a negative going AGC signal provided from a conventional diode envelope detector, or to the left of the crossover point of Figure 5. However, when used as an autocorrelator, it can provide operation with either polarity. The best hard-limiting performance for Loran-C signals is obtained by keeping the AGC DC bias level above the crossover region or in the region of the very steep slope of 100 dB/volt. The exact operating voltage will vary with the particular circuit and the amount of RF gain ahead of the amplifier II limiter. Transformer T5 is similarly very broadband at 100 kHz because of the loading of the primary low impedance winding connected directly across the amplifier pin 15 output terminal. The AGC filtering RC time constants are chosen for a fast attack to pass the rise time of the Loran-C envelope and to decay in less than 1 ms such that single pulse AGC is achieved. The overall circuit gain without AGC feedback is quite high and cannot be determined directlyfor this circuit. (Regeneration or oscillations develop in the completely wideopen loop case at some setting of the threshold and RF gain controls.) We usually mount the threshold control as a front panel control beside the LED and speaker indicators. However, some users might also wish to mount the RF gain control on the front panel as well. Three twisted wires running from the threshold pot connection points on the circuit board to a panel mounted control will be satisfactory with no cross talk for lengths of 6" or so. The front panel should be well grounded to the circuit board. One method is to mount the circuit board on metal standoffs with an L-shaped panel and mounting plate. The use of a mounting plate with standoffs underneath or on the foil side of the circuit board also improves the circuit shielding somewhat.

The polarity of the windings of transformer T5 is critical. The circuit board is prepared for use with an 80IF103 transformer from Mouser Electronics Company, 11511 Woodside Avenue, Lakeside, California 92040. If another transformer is substituted here it might be necessary to break the foil on the PC board and jumper the primary winding in the reverse direction. This will be obvious because the wrong polarity here will produce a negative going signal envelope instead of the positive envelope at the scope monitor point of Figure 3. A negative envelope will generally make the operation unsatisfactory for this particular receiver. However, receiver designers should note that other types of AGC circuits are possible and that this reversible polarity of the output of the multiplier is inherently what is needed when designing a crosscorrelator type of detector with a VCO or digital increment-decrement type of phase locked loop. For the autocorrelator use here a positive-going envelope output signal is required.

The purpose of the tuned circuits and adjustment pots is to shape the input bandwidth to the autocorrelation detector to satisfy the risetime requirement of the transmitted Loran-C signal. Most of the adjustments may be fixed and locked in place for a particular Loran-C chain, with only the threshold pot made available as a front-end sensitivity control. If a user moves about the country over a very wide area, it may be necessary to realign the T-Notch traps to eliminate interference problems. It is also possible to design software type of digital filters to eliminate interference by using the phase code of the Loran-C transmitted signal. Some commercial receivers contain as many as three different receiver front-ends: a narrow band 100 kHz channel for initial acquisition of signals or so called search mode channel, a wide band 100 kHz channel to measure and track the time differences of the pulses, and a third tunable receiver to identify interference with a set of user adjustable traps and null detector only for the bandpass shaping problem. The Mini-L system is obviously much simpler using a single front-end, but with the adjustable threshold it provides an initial search mode, which is then changed by increasing the threshold control setting to limiting or tracking on all signals, and a fixed tuned trap system for a particular area usage.

WIDE BAND NOISE

Another type of interference problem for Loran-C users is wideband noise generated by poorly designed vehicle ignition systems, or 60 Hz AC power line solid state control devices and noisy electrical machinery. There is no really good way of completely eliminating this problem except in the receiver software processing which follows the front-end. In the longer range future we may anticipate there will be stricter control over the harmonic radiation produced by these electrical devices as is already the case in the spurious radiation produced by poorly designed TV sets or CB transmitters subject to FCC regulations. It is a relatively simple problem to cure these harmonic or noise radiating devices, such as a variable speed electric power drill, at the source with some simple LC filtering. This should be a Federal requirement in the future. Federal regulations on the use of 100 kHz to 200 kHz carrier current receiver-transmitters used for information transmission by many power companies will also be subject to change as the community of Loran-C users increases across the continental and coastal regions of the USA. There is no fundamental reason why this service cannot be restricted to channels well-removed from Loran-C and equipment be required to be non-radiating with better control of the grounding of AC power line systems.

DIGITAL OUTPUT AND INDICATOR CIRCUITS

In the initial testing of the Mini-L front-end, an oscilloscope is required as the tuning indicator. Earlier types of Loran-A sets often used a scope as the basic display and time interval measurement device. A scope is a very useful accessory to any Loran receiver system; however, many users view this as undesirable and prefer some form of automated pushbutton operation. This is a very difficult problem to solve in a truly low-cost RF front-end for Loran-C. An oscilloscope is by far the most useful single measuring tool available to monitor a variety of receiver performance factors. There is no reason why marine systems could not be required to have an auxiliary scope monitor display for the observer to monitor interference. However, this is usually not the case.

A simple LED indicator and audible signal level detector are used in the Mini-L front-end. An expanded sketch of the pulse envelope waveform as observed at the envelope scope monitor point (C) of Figure 3, is shown in Figure 6 along with some examples of the raw signal envelope observed for the East Coast Loran-C chain in the Mini-L receiver. The peak-to-peak amplitude of these signals is of the order of 0.7 Volt. In the Mini-L design a single comparator with an automatic level control set at about the 50% amplitude level of the rising pulse envelope, is turned on providing an amplitude gate for all signals above this trigger point. The threshold control of the receiver is adjusted such that all the signals are triggering at this point along with some of the baseline noise. This operational point can be detected without an oscilloscope by using the indicator circuit of Figure 7. A transistor drives an LED and miniature loudspeaker voice coil connected in series. The LED will be observed to flicker at the GRI rate at a low threshold when the comparator from point (C) is only firing on the strongest signal and a faint 10 Hz clicking rate can be heard in the loudspeaker. As the threshold control is advanced, a fuller clicking rate can be heard and the LED will glow very brightly. By backing off slightly from this maximum limiting condition, a point will be found where a slight flickering of the LED combined with a good full sound of many Loran-C signals can be recognized. In the early stages the user should observe an oscilloscope display at point (C) while simultaneously viewing the LED and listening to the loudspeaker noise phenomena. With very little practice it will be found quite easy to adjust the AGC threshold level control pot for limiting on all signals when the noise level is observable but just below the 50% trigger point, or more signals than hiss can be heard in the loudspeaker. This point is what we will call the tracking mode adjustment of the Mini-L when all signals that are usable will be firing the envelope comparator. Some of the unusable signals will also be contaminating here and it is up to the software processor to recognize these (such as Loran-D 16 pulse groups, or the wrong GRI). The RF gain trim pot of Figure 3 should be adjusted for the best signal to noise ratio as observed on an oscilloscope and approached from the ground end of the RF control. This adjustment may then be locked in place and only the front panel AGC threshold control used for receiver level control. Depending on the nature of the software used with Mini-L, the user can also provide a search mode of operation with the threshold control where only the strongest signals are firing the comparator for initial acquisition of the desired chain rate. Then after the chain is locked, the threshold control may be advanced to the full limiting mode using the above LED and loudspeaker indicating method, for tracking operations.

Some further sophistication is desirable to insure that a carrier zero crossing near the 50% level trigger point is the one used for time interval measurements. This is accomplished with the autosynchronizing circuit also illustrated in Figure 7 with a dual type D flip-flop. Another comparator from points (A) and (B) of Figure 3 generates zero crossings of the actual 100 kHz signal. The output of this is used to clock the second type D flip-flop producing only one 10 microsecond pulse for each level change of the envelope signal comparator. These pulses could be used both for interrupt to the microprocessor and to latch a hardware word generator for the time samples from an external clock. The zero crossing outputs as well as the envelope gate are also available on the Mini-L circuit board for whatever the system designer needs.

One problem that many Loran-C receivers have is an erratic 10 microsecond jump in the time measurement. This is sometimes associated with interference or with signal level changes caused by day to night propagation phenomena (skywave-groundwave) differences). The software designer should provide some means of recognizing sudden 10 microsecond jumps in the time intervals and the Mini-L AGC threshold control can be advanced slightly to reduce this effect by increasing the signal level if required. Obviously if the rise time of the signal envelope is not the same for all signals triggering the envelope gate comparator, then the synchronizer will pick the earlier or later 10 microsecond 100 kHz zero crossing. The Mini-L system here depends on the fact that each usable signal should be hard-limiting at the envelope output such that the trigger point of the envelope comparator is the same. Erratic 10-microsecond jumps in the time measurements are an indication of error and should be considered in the software processing design, possibly by supplying an output from the microprocessor back to the receiver user to suggest a faulty setting of the threshold level control pot.

Another problem that the software designer has is the generation of measurement windows around the expected time delay of the desired signals. Signals from interfering chains not at the same GRI or Loran-D will contaminate the desired master and slave transmissions by overlap of the zero crossings. Proper software design should be able to handle this problem.

The envelope gate level comparator driven from point (C) can be adjusted for a slightly earlier or later firing point by adjustment of the 220 k ohm resistor connected as positive feedback. A 150 k ohm resistor will make the firing time later or greater than 50% amplitude and a larger 270 k ohm resistor will make it earlier. It is wise for the experimenter to make some estimates of the risetime of the actual Loran-C signals versus the trigger level of the envelope comparator by using a dual channel oscilloscope and to insure that this trigger point is about the same for all signals that limit. If an error is found the trigger point should be adjusted to fire earlier or the bandwidth of the system changed by retuning. In any case, a resistor of 150 k to 220 k is usually required from pin 1 to 7 of the envelope comparator in Figure 7.

MINI-L CIRCUIT BOARD

The component placement layout of a 3" x 5" circuit board containing the circuits of Figure 3, Figure 7, and a power supply regulator is shown in Figure 8. Figure 9 is the foil side of the circuit board. The +5V regulator can be driven from a filtered raw DC supply of +8 to +12V. The receiver draws only about 50 mA with the LED full on for the signal level indicator so a heat sink for the 7805 regulator is not required. The regulator should be mounted on the top side of the circuit board (component side) with a 4/40 screw and nut fastening it to the ground plane underneath. 1/4" to 3/8" metal standoff spacers and 4/40 screws can be used to mount the circuit board on an appropriate metal surface or minibox.

The input circuit from the preamplifier on the Mini-L circuit board has a low pass filter output which can be used to drive a Mini-O Omega front-end from the same preamplifier. This is labeled OUT on the Figure 8 component placement drawing and OUT to VLF on Figure 3. This feature is provided so that users can expand their system capability from the same antenna installation which will also drive a 10 to 14 kHz Omega front-end such as the Mini-O (see BYTE, March 1977). For Loran-C Mini-L use the gain of the preamplifier is not particularly critical and lower values than suggested in Figure 1 down to a loss of -6 dB can be tolerated with antenna lengths of 1 meter or more. However, for Omega with the original Mini-O receiver as described in BYTE for March 1977, a gain of 6 dB or more is desirable. The gain of the preamplifier can be increased slightly by changing the 680 ohm resistor on the Mini-L circuit board to 1 k, but is mostly a function of the MPF102 JFET used. Variations of voltage gain in this circuit from 0 dB to +10 dB are observed with a random sampling of the transistors. This is of no consequence for Loran-C where the Mini-L system is designed with excess gain for hard-limiting.

COMPONENT PARTS LIST FOR MINI-L

For preamplifier and front-end PC board less mounting hardware and boxes.

QUANTITY REQUIRED	ITEM		EST. COST
25 resistors	¼ watt, 5% miniature carbon film resistors or carbon composition types in following values: 1-100, 2-470, 1-330, 1-680, 6-1k, 1-2.2k, 2-2.7k, 1-3.3k, 3-10k, 3-15k, 1-150k, 1-220k, 1-470k, 2-1m. MOUSER Part # 29SJ250, ¼ w, 5% carbon film.	@ .10 ea.	$ 2.50
trim pots			
2	CTS type, Mouser part #32KA205 500 ohm	@ .39 ea.	
2	CTS type, Mouser part #32KA401 10k ohm	@ .39 ea.	
1	Mouser part #31VC301 1k ohm panel mount pot (suggested for threshold control)	@ .79 ea.	$ 2.35
capacitors			
3	Mouser 23PS233 .0033 mf polystyrene 50V	@ .16 ea.	
10	Mouser 21KC010 .01 mf ceramic 25V	@ .16 ea.	
3	Mouser 21KC005 .005 mf ceramic 25V	@ .15 ea.	
1	Mouser 21KC001 .001 mf ceramic 25V	@ .15 ea.	
3	Mouser 21KC050 .05 mf ceramic 25V	@ .18 ea.	
1	Mouser 21CA500 500 pf ceramic 50V	@ .18 ea.	
1	Mouser 18EM447 0.47 mf dipped tantalum	@ .35 ea.	
6	Mouser 18EH610 10 mf dipped tantalum	@ .47 ea.	
1	Mouser 20WK100 100 mfd 25V electrolytic	@ .29 ea.	$ 6.86
transformers 5	Mouser 80IF103, 455 kHz AM IF transformer 25k to 5k output type	@ .59 ea.	$ 2.95
speaker			
1	Mouser 25SP015 miniature 8 ohm, 1.5"diam.	@ .99 ea.	$ .99

NOTE: Above parts are all available from Mouser Electronics, 11511 Woodside Avenue, Lakeside, California 92040, but should also be available from other large parts supply houses. (Minimum order usually $20, user pays local sales taxes.)

semiconductors and ICs	Obtain from local parts distributors or mail order suppliers.		
1	7805 5V voltage regulator	$1.75	
1	red LED (suggest Fairchild FTK0020) kit of 10 for $1.00	1.00	
1	MPF102 JFET (for preamplifier)	.50	
1	2N2907 PNP switching type driver	.20	
1	Fairchild μA721 AM-FM IC	4.50	
1	LM339 quad comparator	1.75	
1	CD4049 CMOS hex inverter-buffer	.75	
1	CD4013 CMOS dual D flip-flop	1.00	$11.45

HARDWARE AND SOFTWARE INTERFACE SUGGESTIONS FOR MINI-L

Copies of Loran-C data sheets for the East Coast and West Coast chains are found in Figure 10. These are obtained from the CG-462 manual and the JOIN 23, p. 189, Fall, 1976. For the microprocessor software designer the GRI of 99300 and 99400 are of interest and the coding delays specified for each station. These determine the starting location of the timing windows for measuring the time delays between the master and respective slaves. For additional information consult the CG-462 User Handbook.

Hardware for time-frequency checks on local 1 MHz quartz crystal oscillators can be reasonably simple. A suggested circuit is illustrated in Figure 11. For use only on the East or West coast chains of the USA, a timer with one programmable divider stage is required. The usual method is to provide a down counter from a basic counting rate of 100,000. Thus the basic GRI of the desired chain is obtained with only a few decade counters driven from a standard 1 MHz clock oscillator. The user can set the local clock with respect to one of the stronger Loran-C stations of a particular chain by synchronizing the oscilloscope sweep with the GRI obtained from Figure 11 and observe the Loran-C station signal slowly move to the right or left of any arbitrary starting point. By tweaking (small adjustments in oscillator frequency) the local clock, the apparent drift of the Loran-C signal can be slowed down to where it is effectively standing still for long periods of time. The frequency or time offset of the local clock may be estimated by observing the time elapsed for a given change to the right or left of the oscilloscope sweep position, or $\Delta t/t$ determined directly in this simple experiment.

The microprocessor software designer needs some means of providing Loran-C data to the usual 8 bit data bus. One suggested means is from a binary Loran Word Generator such as shown in Figure 12. This consists of a 17 bit ripple counter with two 4520 binary counters and a single type D (1/2 4013) flip flop. Each 10 microsecond envelope edge generated by the Mini-L front-end clocks the value of the counter outputs into a set of 4076 latches. The outputs of the latches are put out on the microprocessor data lines when the proper address appears on the address bus during the read time of the microprocessor.

The address decode logic provides 2 separate enable lines so that 16 bits of data can be read on an 8 bit data bus. In one particular case only the 4 most significant address bits were used to provide 2 of a possible 16 memory mapped locations similar to the addressing scheme used in the Mini-O interface (see BYTE-April 1977). The 17th and most significant bit of the counter is brought into the processor through one of the PIA input ports, to save hardware. The counter reset is used as a means to reset the counters under software control from a PIA output port.

Thus, in order to get information from the Loran Word Generator, the 10 µs Loran-C envelope pulses from Mini-L, latch the data and also cause an interrupt. The microprocessor interrupt routine then needs to address three memory locations to obtain the data, two for the memory mapped data and one for the PIA input port.

There are other methods of obtaining the data. For example, a BCD word generator operating at an externally programmed GRI similar to Figure 11, might be used to provide the exact chain rates such as 99300 or 99400 microsecond time intervals. The word generator might be synchronized under software control such that exact microsecond time intervals in five BCD words could be read into the microprocessor data bus, requiring three 8 bit latches. Depending on the viewpoints of the software designer and the microprocessor capability to handle BCD words instead of binary, this might be a better method. In any case, from the interface hardware suggested in Figure 11 and Figure 12, the software designer can proceed to invent his own methods of reducing the Loran-C data to useful timing and navigation information.

BASIC LITERATURE FOR BEGINNERS ON LORAN-C

"Loran-C System Characterization", WGA Publication No. 1/1976, September 1976, (Write to Wild Goose Association, 4 Townsend Road, Acton, MA 01720 for price and availability.

"Loran-C User Handbook", CG-462, August 1974. (Write to U.S. Coast Guard Headquarters, Washington, D.C. 20590 for a copy of latest version).

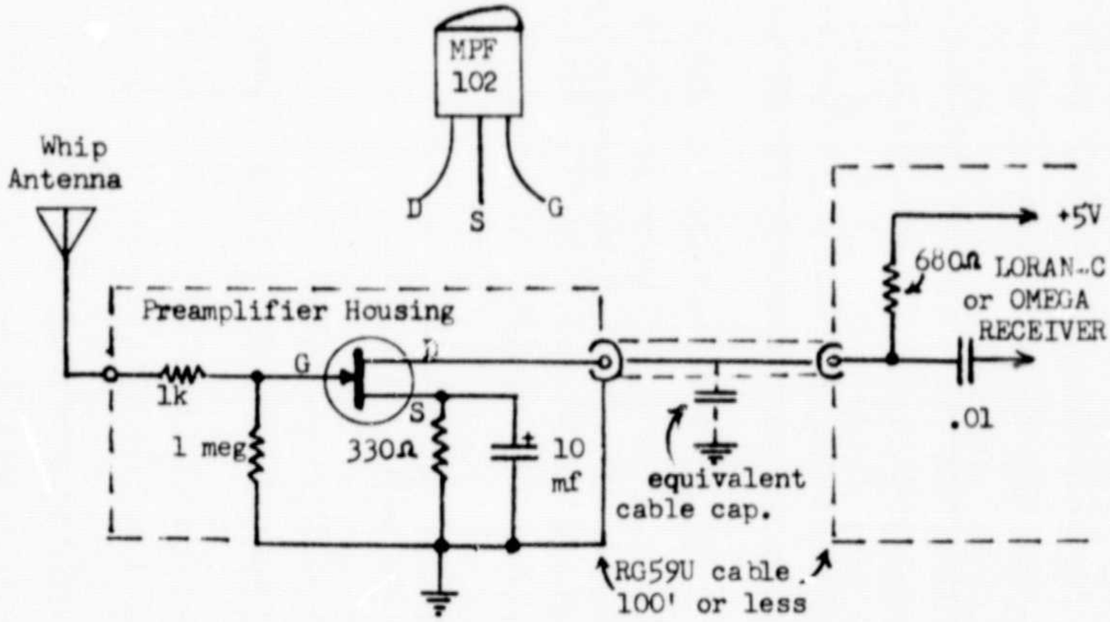
"Loran-C Expansion in the Coastal Confluence Zone", F.W. Mooney, JION, 23, No. 3, pp. 187-190, Fall 1976.

"Loran-C Navigation Charts for the Coastal Confluence Zone", W. B. Ferm, JION, 23, pp. 191-194, Fall 1976.

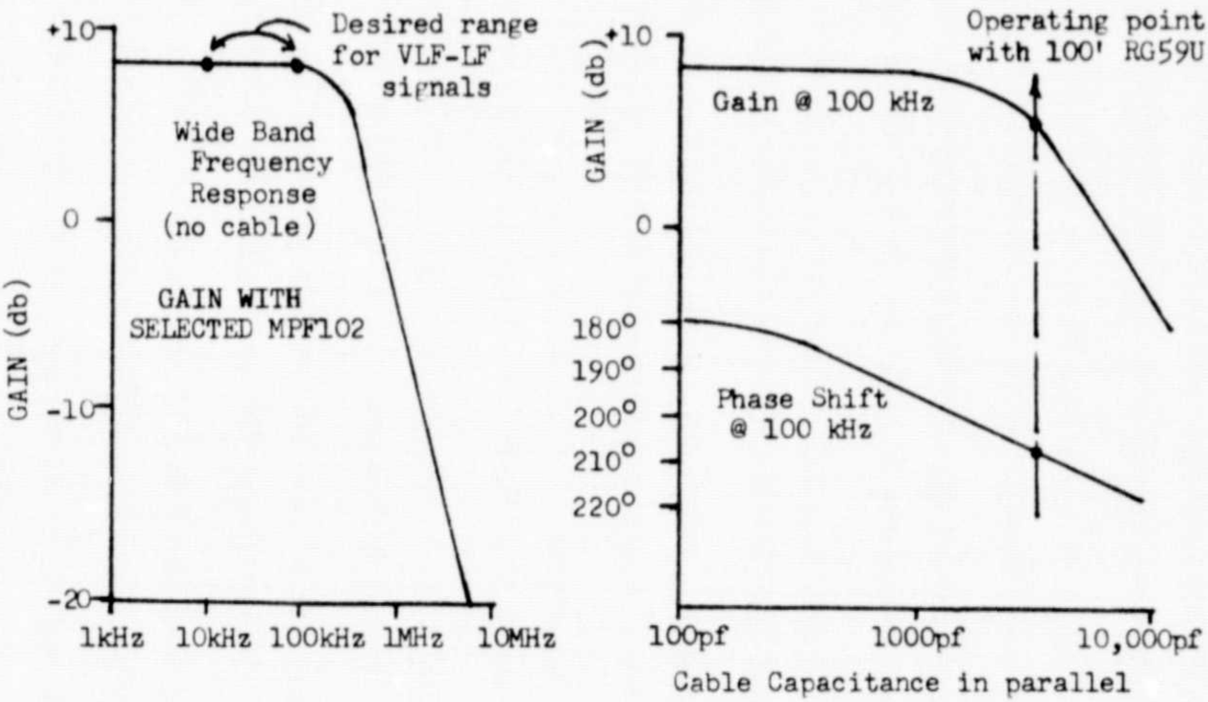
NOTE: Many other papers appear in the Journal of the Institute of Navigation (JION) which should be available at most University or larger public libraries.

"Time Synchronization from Loran-C", L. Dennis Shapiro, IEEE Spectrum, Vol. 5, No. 8, pp. 46-55, August 1968. Note that this paper covers basics of system but includes earlier operation of system with 1 sec. ticks which are no longer available.

"Precise Time and Frequency Dissemination via the Loran-C System", C.E. Potts and B. Wieder, Proc. IEEE, 60, No. 5, pp. 530-539, May, 1972.

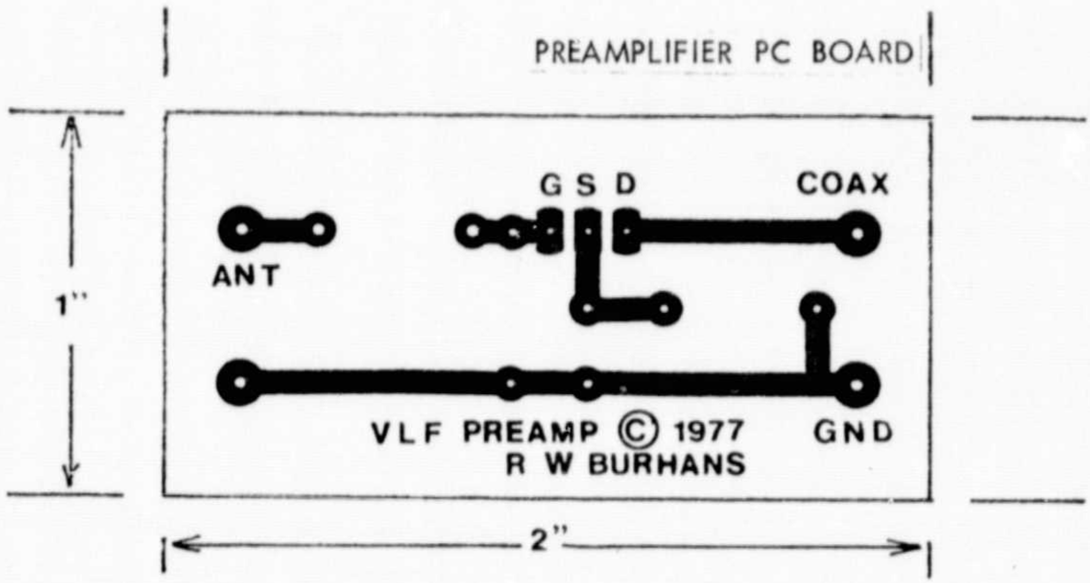


PREAMPLIFIER CIRCUIT

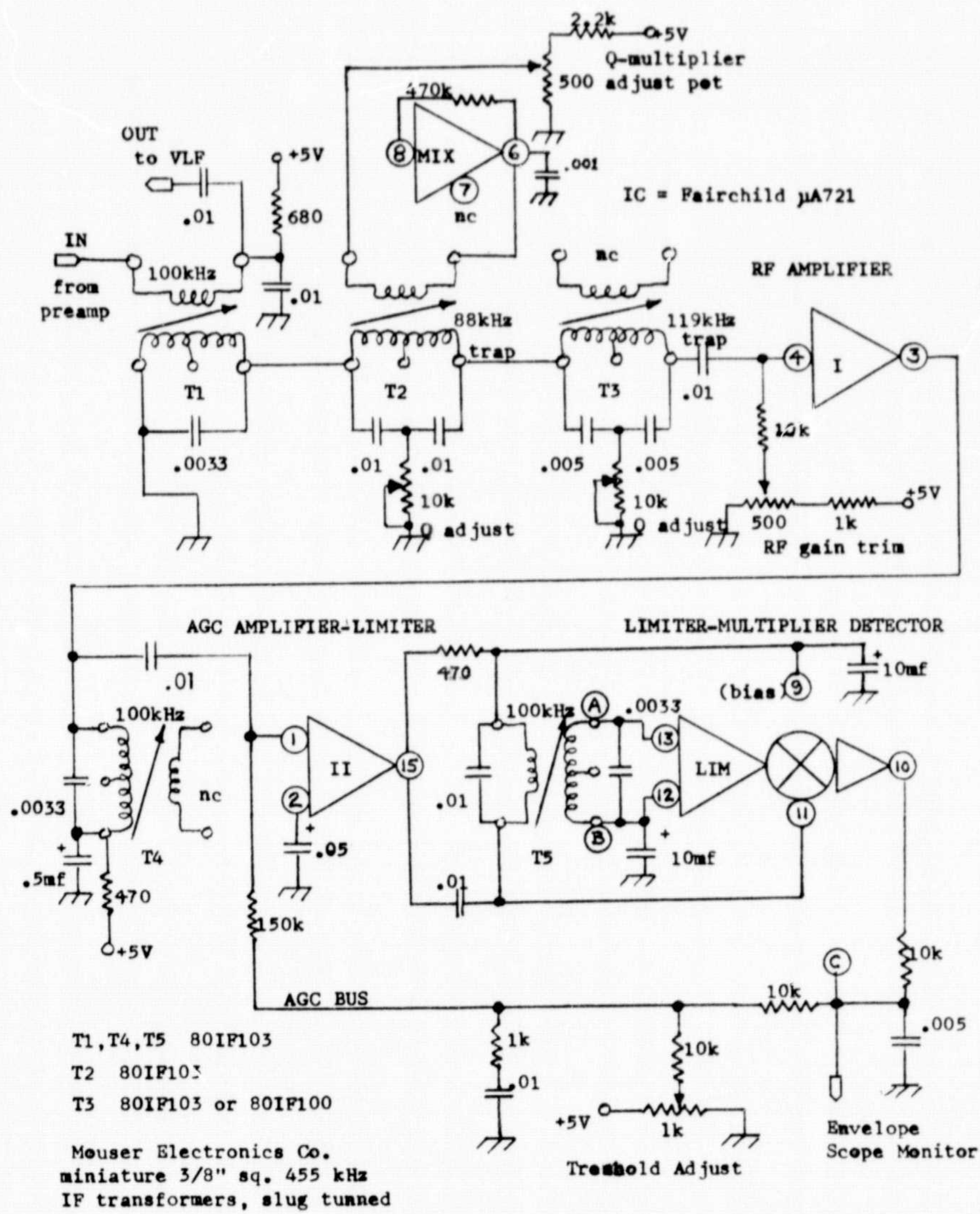


PREAMPLIFIER RESPONSE

FIGURE 1

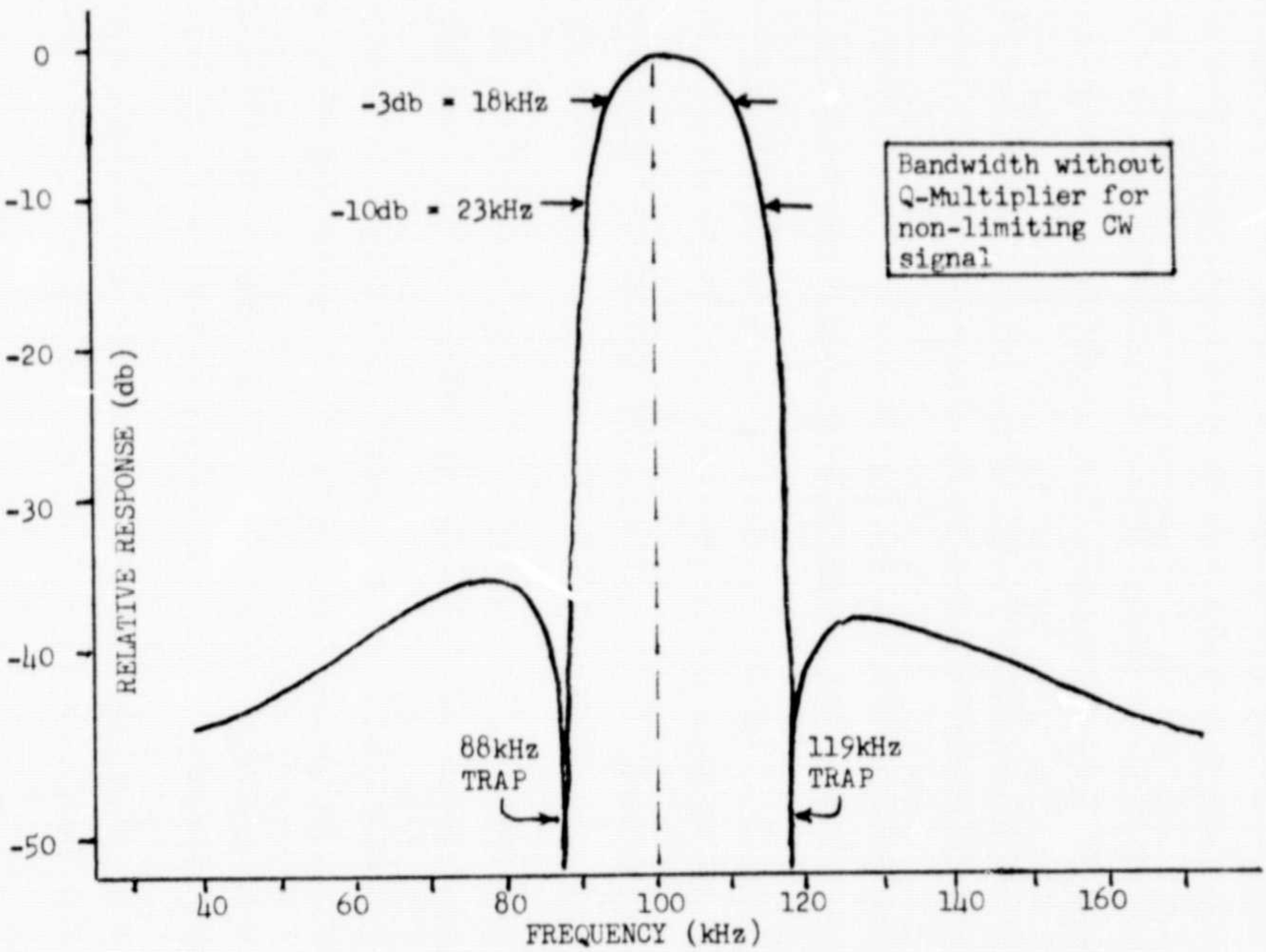


ANTENNA PREAMPLIFIER
FIGURE 2



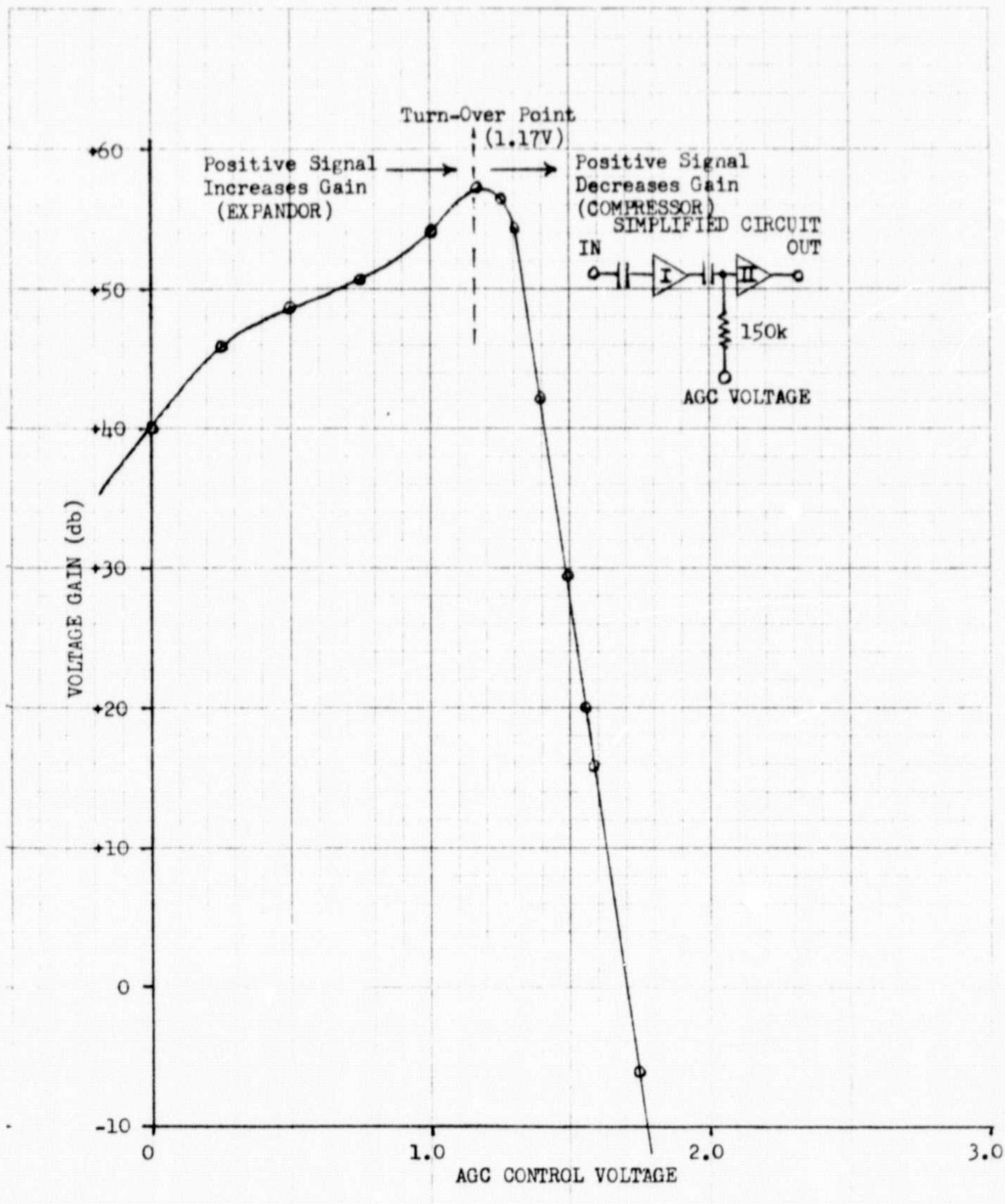
MINI-L LORAN-C RF CIRCUIT

FIGURE 3

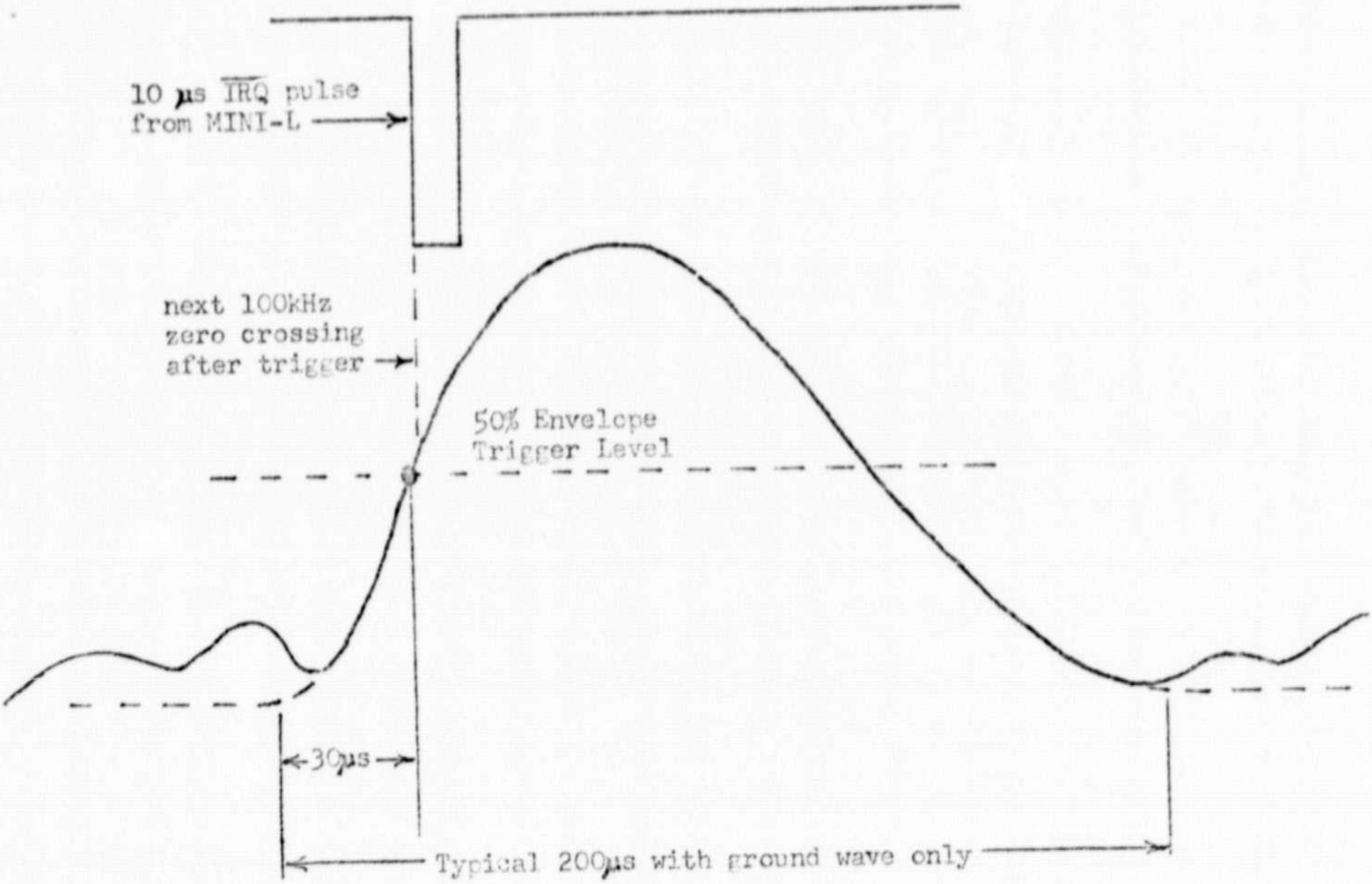


MINI-L INTERSTAGE BANDWIDTH (pin 3, amplifier I)

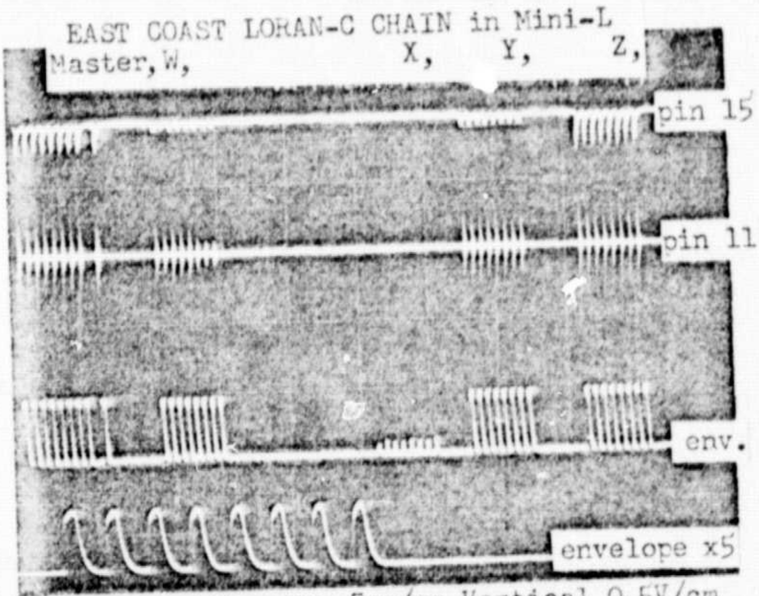
FIGURE 4



MINI-L AGC CHARACTERISTICS
FIGURE 5



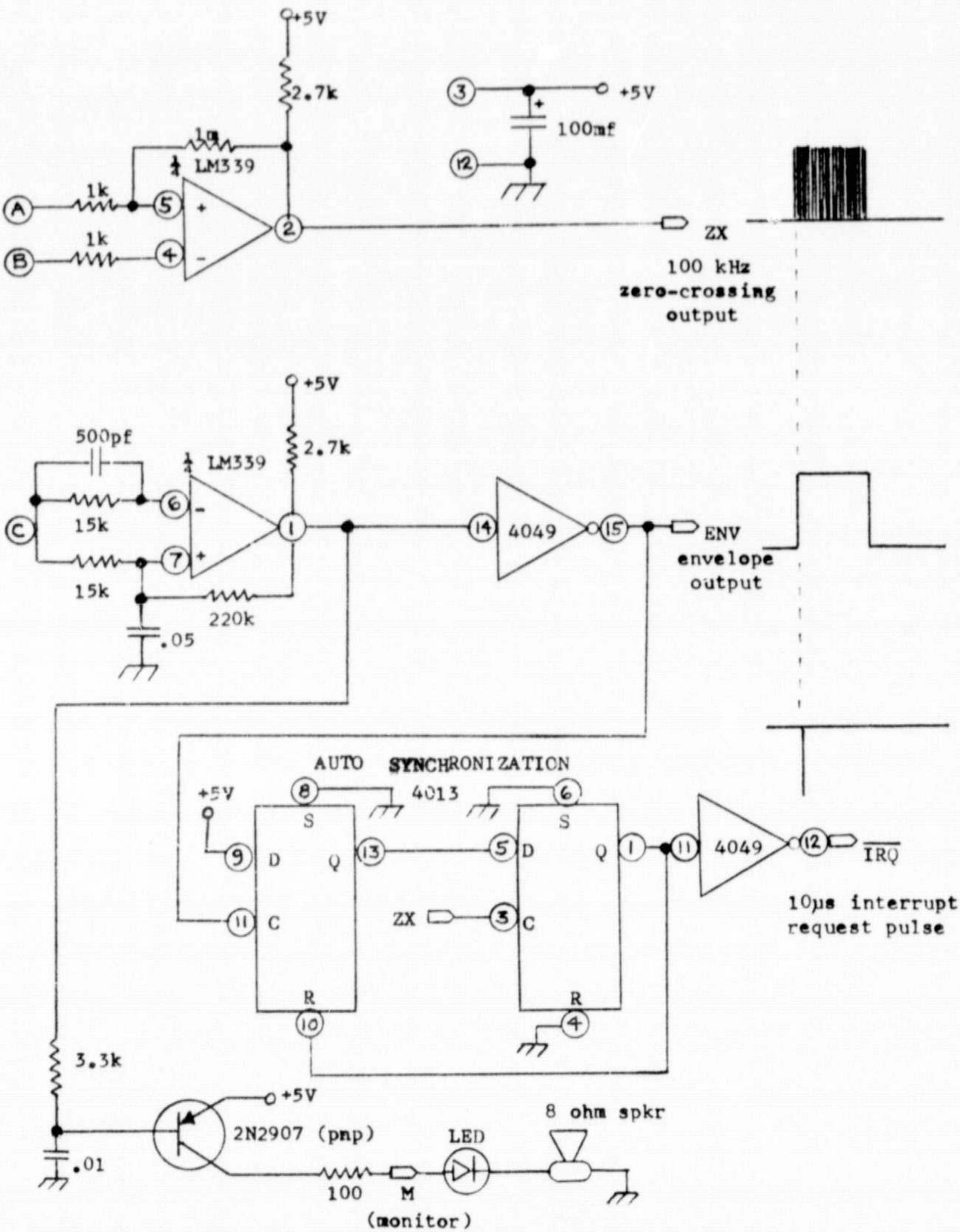
LORAN-C SINGLE PULSE ENVELOPE



Horizontal sweep 7ms/cm, Vertical 0.5V/cm

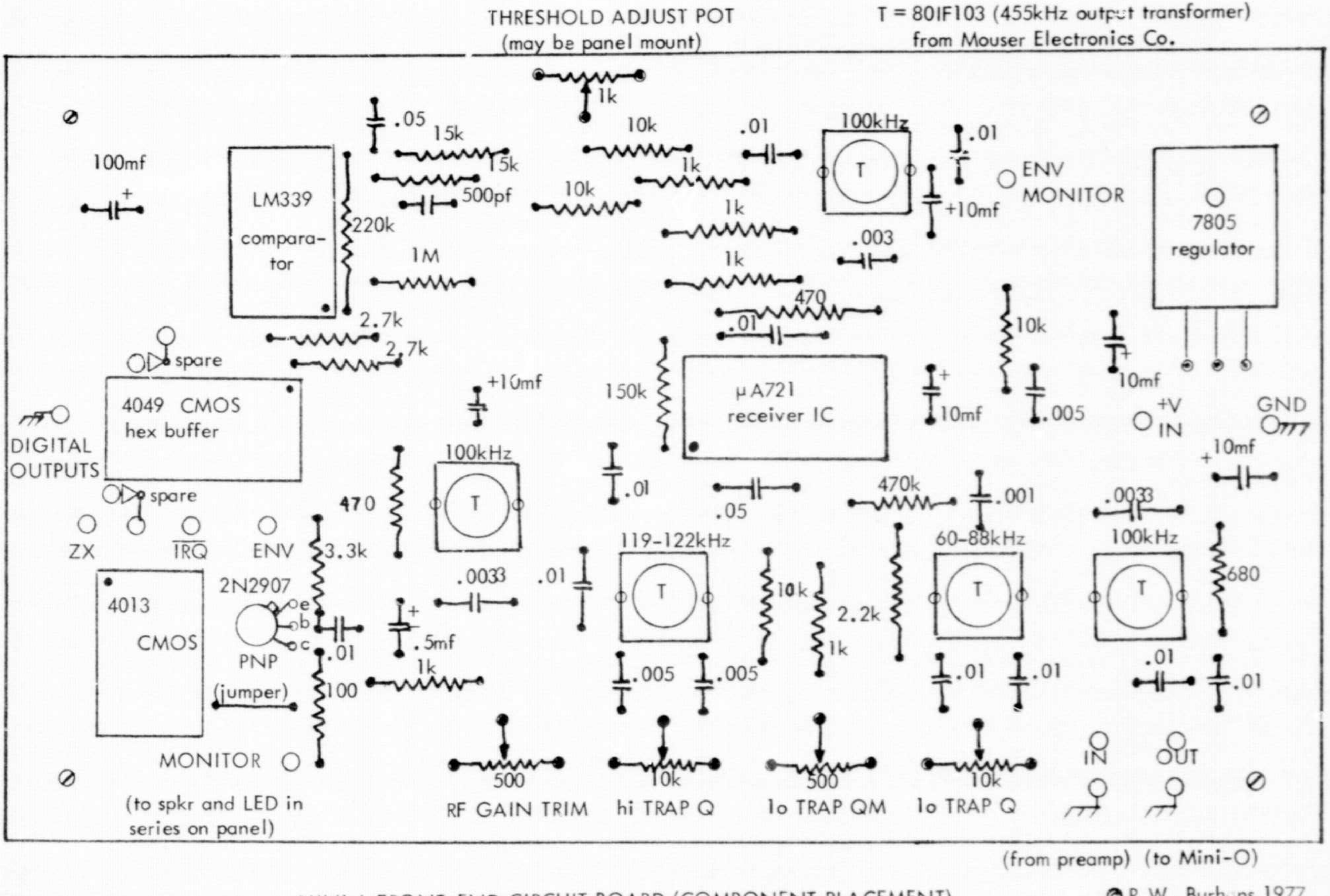
MINI-L ENVELOPE CHARACTERISTICS

FIGURE 6



MINI-L LORAN-C OUTPUT CIRCUIT

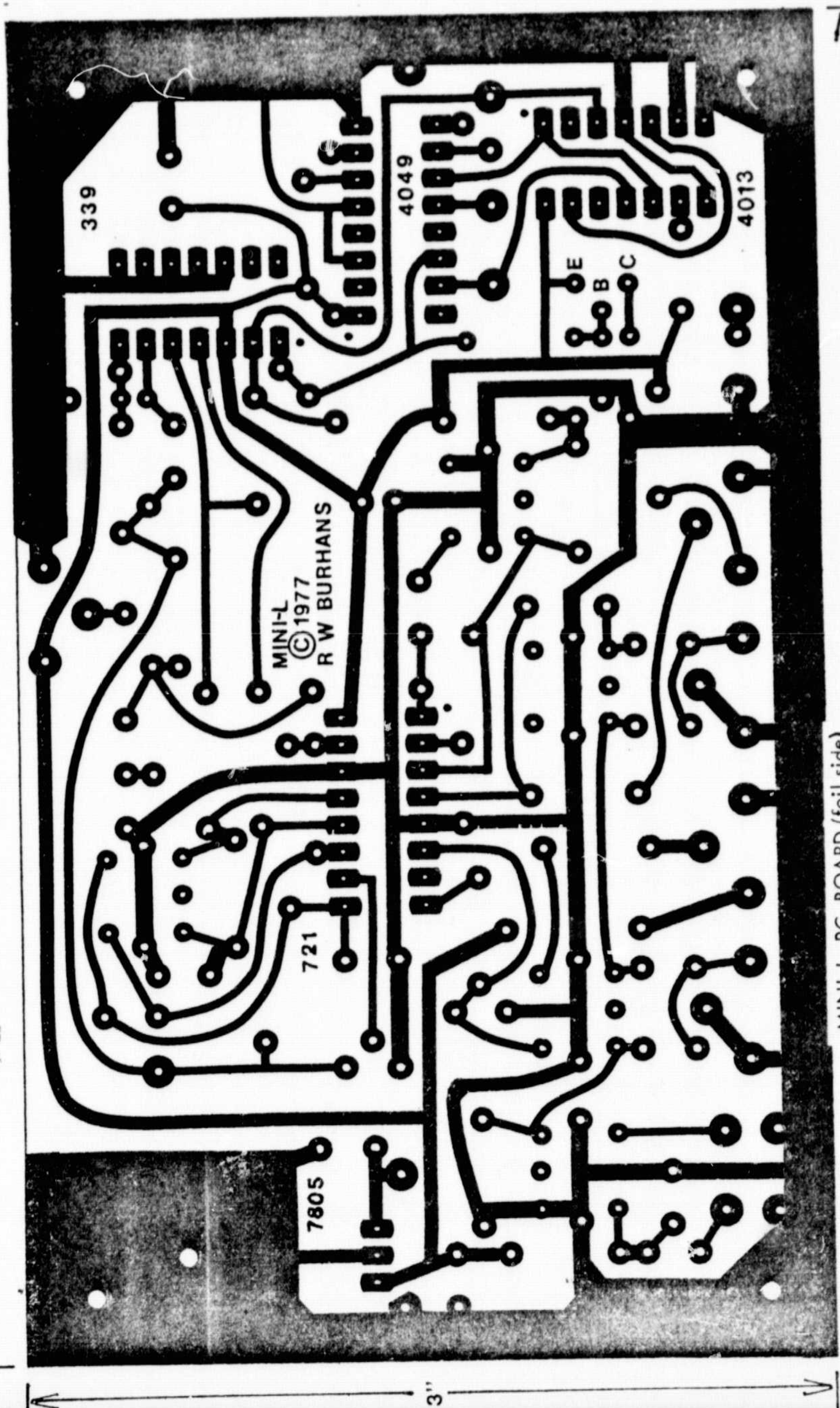
FIGURE 7



MINI-L FRONT-END CIRCUIT BOARD (COMPONENT PLACEMENT)

FIGURE 8

MINI-L PC BOARD



MINI-L PC BOARD (foil side)

FIGURE 9

LORAN-C DATA SHEET
U.S. EAST COAST CHAIN—RATE 9930 (old rate SS7 (99,300 usec))

STATION	COORDINATES LATITUDE & LONGITUDE	STATION FUNCTION	CODING DELAY & BASELINE LENGTH	RADIATED PEAK POWER	REMARKS
CAROLINA BEACH, NORTH CAROLINA	34-03-46.50N 77-54-47.29W	MASTER		1.0 MW	Exercises operational control of chain.
JUPITER, FLORIDA	27-01-58.85N 80-06-53.59W	W Secondary	11,000 us 2695.51 us	400 KW	
CAPE RACE, NEWFOUNDLAND	46-46-31.88N 53-10-29.16W	X Secondary	28,000 us 8389.57 us	2.0 MW	Host nation manned. Double-rated to NORLANT chain (7930)
NANTUCKET, MASSACHUSETTS	41-15-12.29N 69-58-39.10W	Y Secondary	49,000 us 3541.33 us	400 KW	
DANA, INDIANA	39-51-08.30N 87-29-12.75W	Z Secondary	65,000 us 3560.73 us	400 KW	
Electronics Engineering Center, Wildwood, N.J.	38-56-58.59N 74-52-01.94W	T Secondary	82,000 us 2026.19 us	200 to 400 KW	Experimental station. Not normally on air.

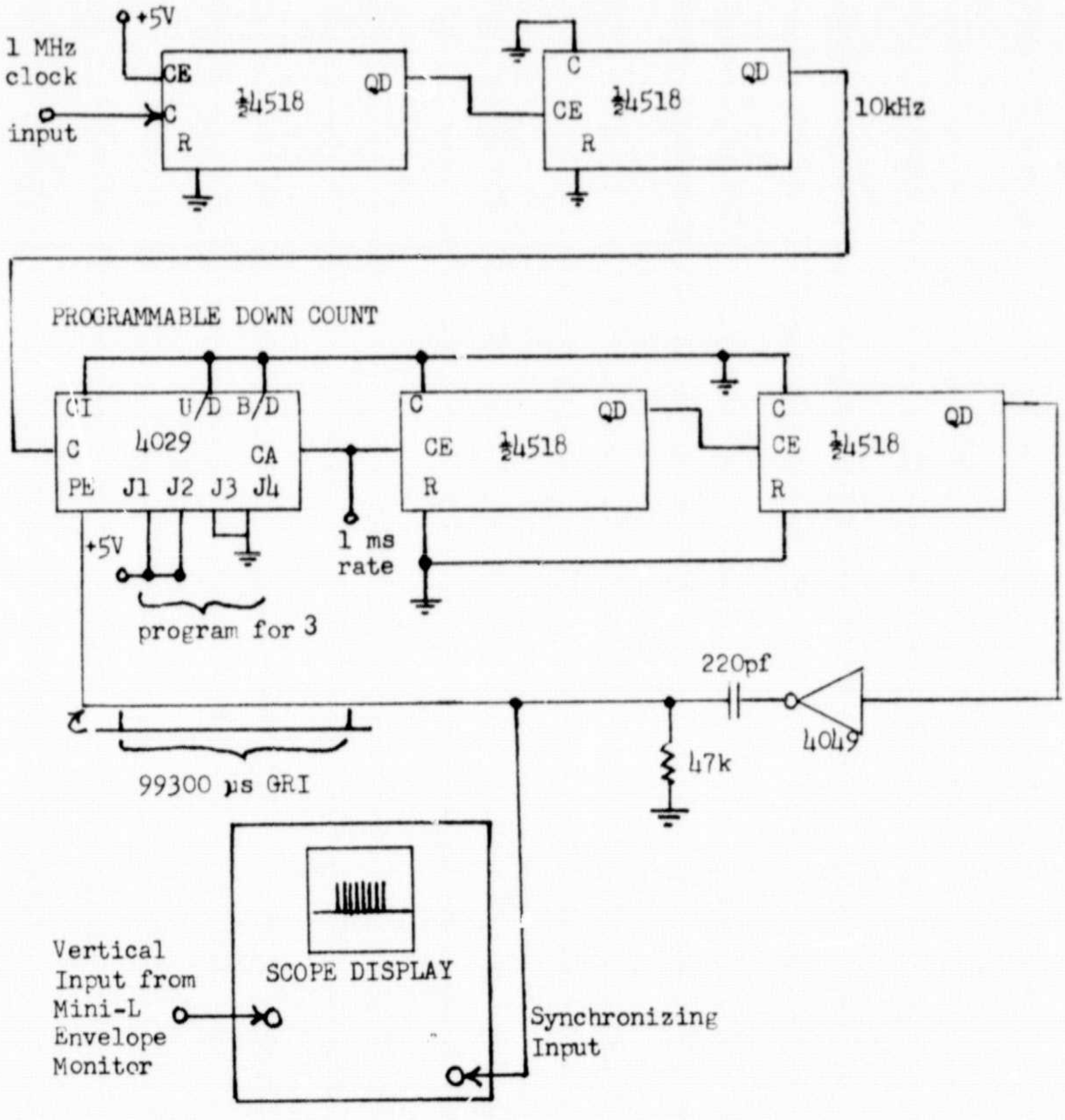
Table 1 – General Characteristics for West Coast/Gulf of Alaska Loran-C Stations

Station	Coordinates Latitude & Longitude(1)	Station Function	Coding Delay	Radiated Peak Power	Primary Power (type)	Antenna	Signal Tests
Fallon, NV	39-33N 118-50W	Master 9940		400 KW	Commercial	625' M(2)	MAY 76
Moses Lake, WA	47-04N 119-45W	W-Secondary 9940 Y-Secondary 5990	11,000 μs 25,000 μs	2 MW	Commercial	TLC(3)	AUG 76
Middletown, CA	38-47N 122-30W	X-Secondary/ Control Stn. 9940	25,000 μs	400 KW	Commercial	625' M	MAY 76
Searchlight, NV	35-19N 114-48W	Y-Secondary 9940	36,000 μs	1 MW	Commercial	TLC	MAY 76
Williams Lake, BC	51-58N 122-22W	Master/Cntrl 5990		400 KW	Commercial	625' M	JUL 76
Shoal Cove, AK	55-26N 131-15W	X-Secondary 5990 Y-Secondary 7960	11,000 μs 24,000	1 MW	Deisel-Electric	TLC	NOV 76
Narrow Cape, AK	57-26N 152-22W	X-Secondary 7960	11,000 μs	400 KW	Diesel-Electric	625' M	NOV 76
Tok, AK	63-20N 142-49W	Master/Contrl 7960		1 MW	Commercial	TLC	DEC 76

Notes
(1) Position to nearest minute.
(2)625' M- 625 foot, top loaded monopole antenna
(3) TLC - 4-700 foot tower, top loaded cone antenna

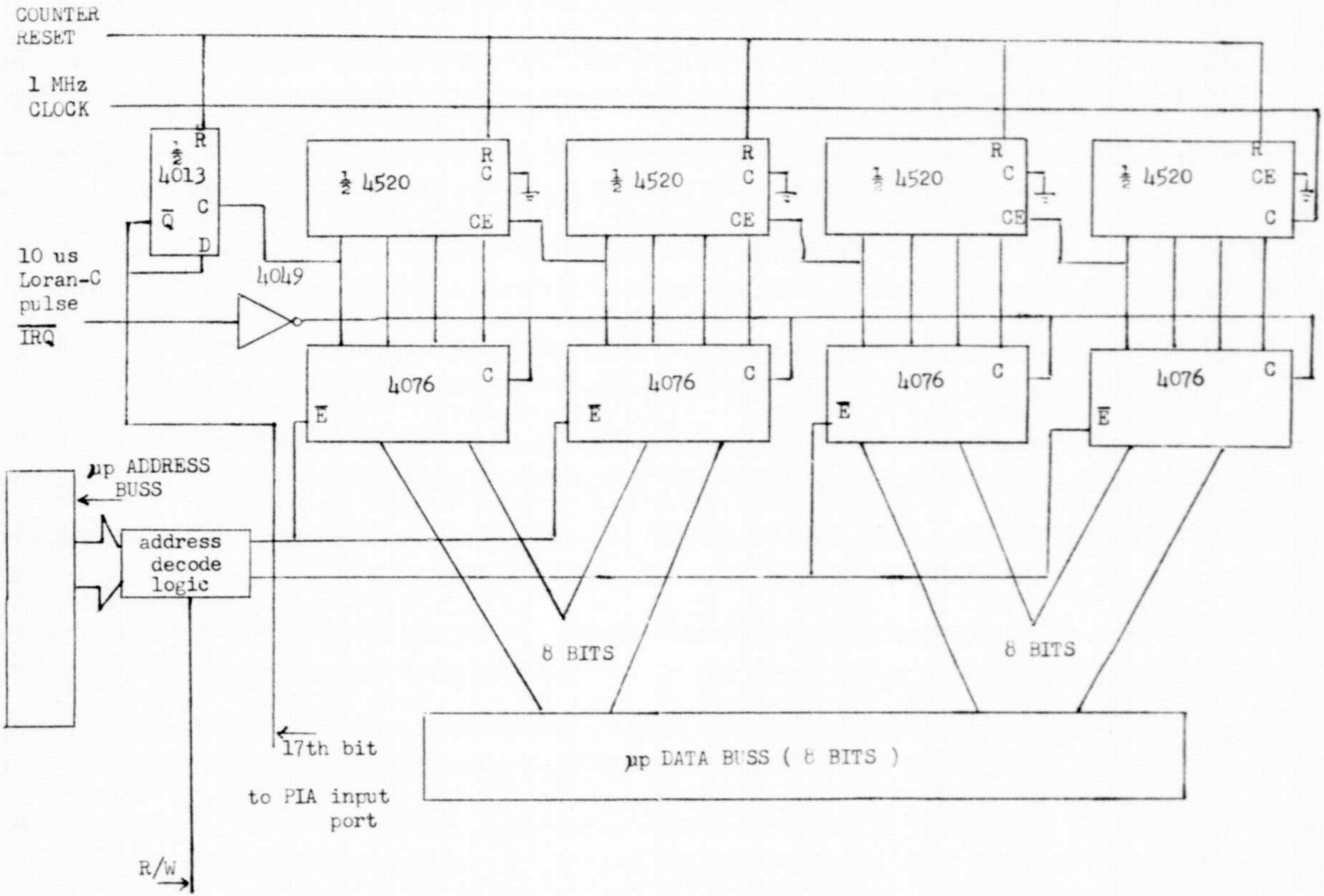
LORAN-C STATION DATA

FIGURE 10



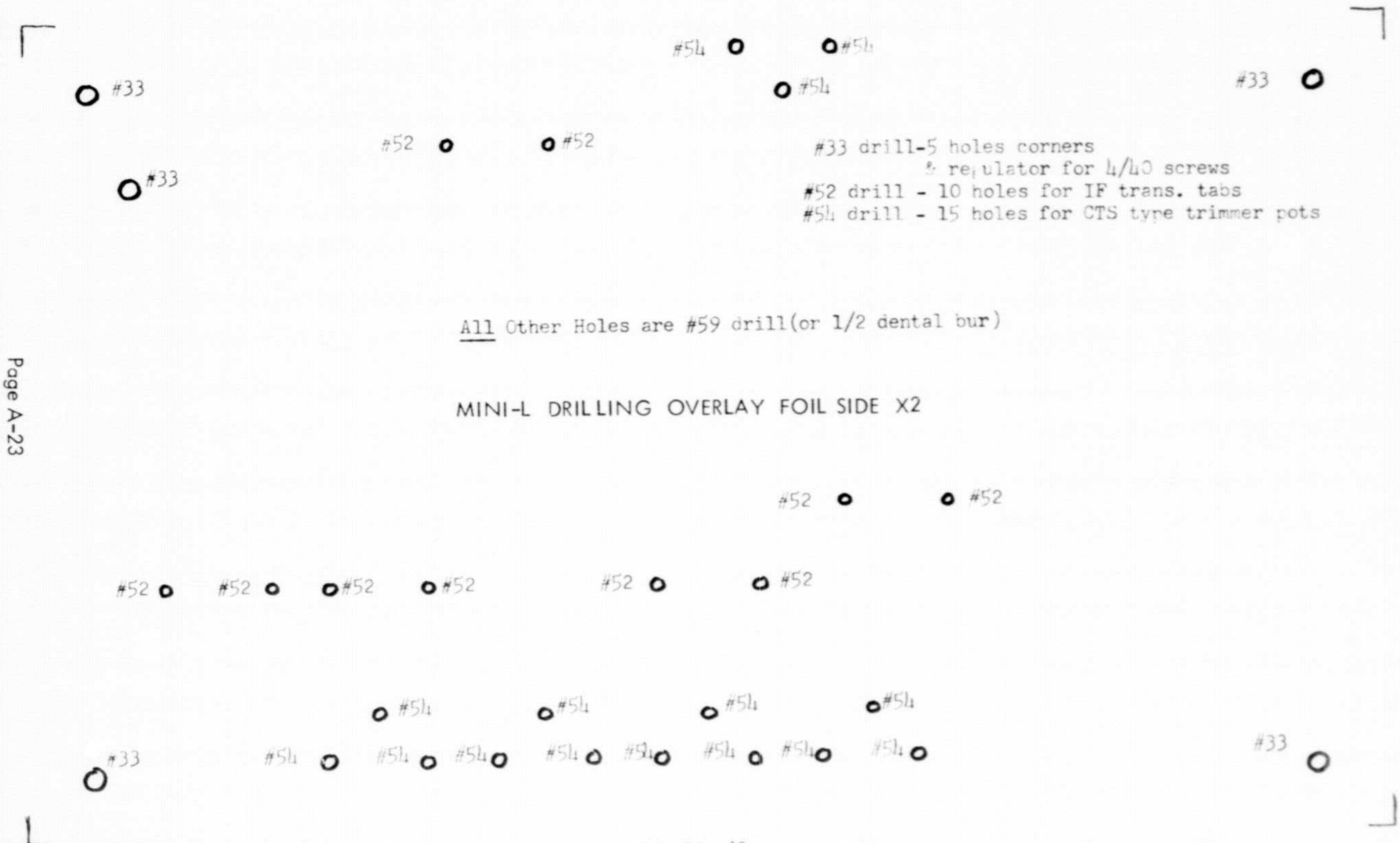
HARDWARE TO SYNCHRONIZE DISPLAY
TO EAST COAST CHAIN RATE

FIGURE 11



LORAN WORD GENERATOR

FIGURE 12



#33 drill-5 holes corners
& regulator for 4/40 screws
#52 drill - 10 holes for IF trans. tabs
#54 drill - 15 holes for CTS type trimmer pots

<u>All</u> Other Holes are #59 drill(or 1/2 dental bur)

MINI-L DRILLING OVERLAY FOIL SIDE X2

FIGURE 13